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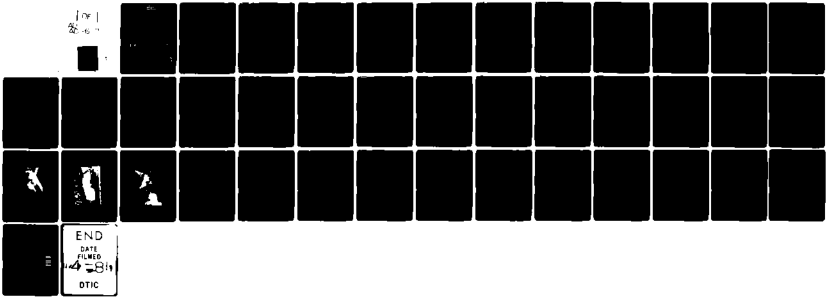

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A NASTRAN INVESTIGATION OF SIMULATED PROJECTILE DAMAGE EFFECTS ON A UH-1B TAIL BOOM MODEL

Arnold T. Futterer

January 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A NASTRAN finite element method analysis was performed on a model of a UH-1B tail boom. Projectile damage was simulated by systematically deleting panels and beam elements. The model was subjected to forces to simulate the flight loads that would be imposed by a 130-knot cruise velocity. Displacements of four points at the base of the vertical fin were used as a measure of loss of structural rigidity. The displacements were measured relative to the unloaded, undamaged state of the tail boom. The analysis was performed

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20. ABSTRACT (continued)

on tail booms constructed of aluminum alloy, then the material constants were changed to represent T300/5208, high-strength Graphite/Epoxy fibrous composite; $[0,\pm 45,90]_s$ for the plate elements, $[0,\pm 45]_s$ for the beam elements.

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I. INTRODUCTION

This investigation had a twofold objective:

1. To determine the effects of threat projectile damage on the structural rigidity of the UH-1B tail boom under flight loads. If the tail rotor drive shaft coupling is too greatly misaligned it will fail under load resulting in the loss of the helicopter.

2. To estimate the effect on the rigidity of the tail boom of replacing the aluminum alloy in the structure with T300/5208, graphite/epoxy fibrous composite material.

The model of the UH-1B tail boom used in the analysis was originally prepared under contract by Kamen AviDyne[1] (KAD) for the Ballistic Research Laboratory. The model consisted of beams representing the stringers, bulk heads, and longerons and of thin plates representing the skin. The KAD report describes the model in good detail. Figures 1-4 are from that report. For further detail on the assumptions that went into preparing the model it is recommended that a copy of the report be obtained from the Defense Technical Information Center*. Figure 1 gives the tail boom stations with side and top views of the tail boom. The skin is made of 2024 T3 aluminum alloy with a modulus of elasticity of 7.31×10^4 MPa (10.6×10^6 psi) and a mass density equal to 2.672×10^3 kg/m^3 (0.00025 lb sec^2/in^4). The stringers, bulk heads, and longerons are made of 7075 T6 aluminum alloy with a modulus of elasticity of 7.10×10^4 MPa (10.3×10^6 psi) and a mass density of 2.672×10^3 kg/m^3 (0.00025 lb sec^2/in^4). Figures 2-4 illustrate the NASTRAN model developed by KAD and give the numbering schemes for the grid points, beam elements, and plate elements, respectively.

II. PROCEDURE

The investigation was accomplished by using the NASTRAN[2] code, a complex computer program employing the finite element method. NASTRAN calculations for static analysis were performed, 17 for the aluminum alloy construction and 18 for the same structure but using the material

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[1] Raffi P. Yeghiayan," Modeling of the UH-1B Tail Boom for Analysis by the NASTRAN Computer Program", Ballistic Research Laboratory Contract Report 00358, Kamen AviDyne, Burlington, MA, Feb 1978, AD#A052303

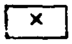
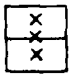
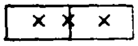
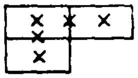
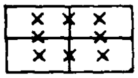
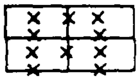
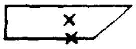
[2] The NASTRAN User's Manual (Level 17.0), National Aeronautics and Space Agency Special Report 222(04), Wash., DC, Dec 31, 1977

*Cameron Station, Alexandria, VA 22314

properties of T300/5208 high strength, graphite-epoxy fibrous composite. The relative displacements of the four points at the rear of the tail boom, with the front of the tail boom fully constrained, were used as a measure of the deterioration of the structural rigidity of the tail boom due to projectile damage. These displacements were compared with the non-damaged, non-loaded tail boom. The flight loads that would be imposed on a helicopter cruising at 130 knots were simulated by loading the structure to simulate the loads and torques that the rotor thrust and elevator would cause at cruise velocity. The assumption was made that a large hole or tear in a skin panel or a break in a longeron, stringer, or bulk head section would destroy the structural integrity of the element representing that skin panel or section. In the model, that damaged element was then deleted. The investigation was conducted by systematically deleting panels and bar elements to simulate greater damage. Damage to the left and to the right side of the tail boom, looking forward, were studied because the right side has thicker skin than the left side. Furthermore, the longitudinal strains were generally compressive on the right side and tensile on the left side. In Table I, the numbers of the elements deleted refer to Figures 3 and 4. As may be noted, the 100 and 200 series numbers refer to the bar elements and the 400 series to the plate elements. Figures 3 and 4 used in conjunction with Table I make it possible to visualize which structural elements of the helicopter were deleted.

Figures 5-7 are pictures of UH-1B tail booms that were used in experiments some years back (about 1975), when 23 mm explosive projectiles were fired at tail booms. The damage configurations as selected for investigation with the present finite element method are therefore typical of the damage to be expected. Generally, there is a small hole on the side where the projectile entered; the heavy damage is to the opposite side when the delay-fused projectile explodes inside the tail boom and sends the blast force and fragments in a forward cone. In the experimental investigation, the damage did not result in structural failure of the tail boom for the damage pictured in Figures 5-7. However, the question was raised as to whether the loss of rigidity could result in misalignment of the drive shaft and damage to the rotor drive shaft coupling with resultant failure of the drive shaft and loss of the helicopter. Configurations 1 through 6, Table I, are typical of Figures 5 and 6 where the damage is to a forward portion of the tail boom. Configurations 7 and 8 are typical of Figure 7 where the damage is to the rear of the tail boom. Tables were constructed to give the displacements of the points at the rear of the loaded, undamaged tail boom and the loaded tail boom with simulated damage relative to the undamaged, unloaded state. The heading "Nomenclature" is defined in Table I. "Material Lost" refers to the mass of the deleted elements. "Direction", "X", "Y", and "Z" gives the displacement of the grid points in the three coordinate directions shown on Figure 2 and "R", which is the square root of the sum of the squares of the three coordinate displacements, gives the total displacement of the grid points specified. The

Table I. Nomenclature for Damage Configurations that were Investigated

Nomenclature	Left(L) or Right(R) side	Deleted Elements	Configuration
0		No elements deleted	
1	L	413	
	R	419	
2	L	413,136,414	
	R	419,141,418	
3	L	413,147,425	
	R	419,153,431	
4	L	425,147,413,136,414	
	R	431,153,419,141,418	
5	L	413,147,425,160,426,148, 414,136	
	R	419,154,431,165,430,153, 418,141	
6	L	413,147,425,160,426,161, 148,137,414,136	
	R	419,154,431,165,430,164, 153,140,418,141	
7	L	456	
	R	458	
8	L	456,221	
	R	458,222	

displacements are given in millimetres and inches. The values of the displacements are given in an exponential format, i.e., 2.05-2 means 2.05×10^{-2}.

III. DISCUSSION OF RESULTS

Table II contains the results of the calculations for the tail boom constructed of aluminum alloy with the damage to the right side of the helicopter. Examination of the Table reveals that the total displacement of any of the reference grid points is at most 13.2 mm (0.521 in.). Figure 8 is a graph of the total deflection of points on the rear of the tail boom versus mass of aluminum alloy removed from the forward right side of the tail boom. As may be noted, the deflection is quite linear with mass removed until about 1 kg. Then with further removal the displacements become nonlinear suggesting a more rapid approach to failure with further loss of material. Table III contains the results of calculations for the tail boom constructed of aluminum alloy but with the damage now to the forward left side. Maximum displacement of the reference grid points for the configurations investigated was 11.6 mm (0.456 in.) Figure 9 is a graph of deflection of points on the rear of the tail boom versus loss of mass of aluminum alloy removed from the forward left side of the structure. Due to the lighter weight panels on the left side, the material loss never exceeded 1 kg, and there was no evidence of nonlinear behavior to greater displacement with further material loss. In fact, the displacement of the points tend to flatten out with loss above 0.54 kg (1.18 lb) and rise less rapidly. This seems to be related to a structural rather than material response since it also appears in a subsequent response to damage on the left side with the structure made of composite material.

After calculating the displacements for the various damage configurations with the tail boom constructed of aluminum alloys, the calculations were repeated using the material properties of T300/5208 which is a high-strength, graphite-epoxy, fibrous composite. The skin plates were assumed to be constructed of $[0,\pm45,90]_s$ layered composite and the beam elements of $[0,\pm45]_s$ layered composite. T300/5208 was recommended[3] as being high strength and considerably less expensive than the ultra-high modulus graphite-epoxy. Since the composites have less strength in compression than in tension, the material moduli of elasticity for both states were used in the calculations. For damage on the left side the tensile moduli were used, 5.59×10^4 MPa (8.11×10^6 psi) for the plate elements and 6.50×10^4 MPa (9.42×10^6 psi) for the beam elements. For damage on the right side the compressive moduli were used, 5.38×10^4

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[3] Private communication with Mr. Michael Duhl, Air Force Material Laboratory, Wright Patterson Air Force Base, Dayton, OH.

Table II. Damage to Right Side of Helicopter Tail Boom Constructed of Aluminum Alloy

Nomen- clature	Material Lost lb/kg	Direc- tion	Grid Point Displacements							
			67		70		71		72	
			in.	mm	in.	mm	in.	mm	in.	mm
0	.0	X	2.18-2	5.54-1	2.45-3	6.22-2	7.52-3	1.91-1	-1.23-2	-3.12-1
	.0	Y	3.30-1	8.38+0	3.30-1	8.38+0	3.23-1	8.20+0	3.23-1	8.20+0
		Z	-2.22-1	-5.64+0	-2.47-1	-6.27+0	-2.46-1	-6.25+0	-2.70-1	-6.86+0
		R	3.98-1	1.01+1	4.12-1	1.05+1	4.06-1	1.03+1	4.21-1	.07+1
1	.71	X	2.17-2	5.51-1	2.02-3	5.13-2	7.35-3	1.87-1	-1.27-2	-3.23-1
	.32	Y	3.36-1	8.53+0	3.36-1	8.53+0	3.29-1	8.36+0	3.29-1	8.36+0
		Z	-2.24-1	-5.69+0	-2.50-1	-6.35+0	-2.50-1	-6.35+0	-2.74-1	-6.96+0
		R	4.04-1	1.03+1	4.19-1	1.06+1	4.13-1	1.05+1	4.28-1	1.08+1
2	1.46	X	2.14-2	5.44-1	2.21-3	5.61-2	6.49-3	1.65-1	-1.49-2	-3.78-1
	.66	Y	3.60-1	9.14+0	3.60-1	9.14+0	3.53-1	8.97+0	3.53-1	8.97+0
		Z	-2.36-1	-5.99+0	-2.64-1	-6.71+0	-2.62-1	-6.65+0	-2.88-1	-7.32+0
		R	4.30-1	1.09+1	4.46-1	1.13+1	4.40-1	1.12+1	4.56-1	1.16+1
3	1.46	X	2.17-2	5.51-1	1.55-3	3.89-2	7.29-3	1.85-1	-1.31-2	-3.33-1
	.66	Y	3.43-1	8.71+0	3.43-1	8.71+0	3.34-1	8.48+0	3.34-1	8.48+0
		Z	-2.28-1	-5.79+0	-2.55-1	-6.48+0	-2.53-1	-6.43+0	-2.79-1	-7.09+0
		R	4.12-1	1.05+1	4.27-1	1.08+1	4.19-1	1.06+1	4.35-1	1.10+1
4	2.33	X	2.13-2	5.41-1	-1.99-3	-5.05-2	6.63-3	1.68-1	-1.50-2	-3.81-1
	1.06	Y	3.64-1	9.25+0	3.64-1	9.25+0	3.54-1	8.99+0	3.54-1	8.99+0
		Z	-2.40-1	-6.40+0	-2.70-1	-6.86+0	-2.66-1	-6.76+0	-2.94-1	-7.47+0
		R	4.36-1	1.11+1	4.53-1	1.15+1	4.43-1	1.13+1	4.60-1	1.17+1
5	3.00	X	2.12-2	5.38-1	-1.24-3	-3.15-2	6.04-3	1.53-1	-1.64-2	-4.11-1
	1.36	Y	3.78-1	9.60+0	3.78-1	9.60+0	3.69-1	9.37+0	3.69-1	9.37+0
		Z	-2.51-1	-6.38+0	-2.82-1	-7.16+0	-2.77-1	-7.04+0	-3.06-1	-7.77+0
		R	4.54-1	1.15+1	4.72-1	1.20+1	4.61-1	1.17+1	4.79-1	1.22+1

Table II Cont. Damage to Right Side of Helicopter Tail Boom Constructed of Aluminum Alloy

[illegible]	Material Lost lb/kg	Direction	Grid Point Displacements 67 in.	mm	70 in.	mm	71 in.	mm	72 in.	mm
6	3.90	X	2.12-2	5.38-1	-3.25-3	-8.25-2	4.45-3	1.13-1	-1.96-2	-4.98-1
	1.77	Y	4.08-1	1.04+1	4.08-1	1.04+1	4.02-1	1.02+1	4.02-1	1.02+1
		Z	-2.73-1	-6.93+0	-3.04-1	-7.72+0	-3.01-1	-7.65+0	-3.31-1	-8.41+0
		R	4.91-1	1.25+1	5.09-1	1.29+1	5.02-1	1.28+1	5.21-1	1.32+1
7	3.18	X	2.62-2	6.65-1	-6.38-4	-1.62-2	8.04-3	2.04-1	-1.07-2	2.72-1
	1.44	Y	3.51-1	8.92+0	3.51-1	8.92+0	3.03-1	7.70+0	3.03-1	7.70+0
		Z	-2.47-1	-6.27+0	-3.33-1	-8.46+0	-2.74-1	-6.96+0	-3.48-1	-8.84+0
		R	4.31-1	1.09+1	4.84-1	1.23+1	4.09-1	1.04+1	4.61-1	1.17+1
8	4.25	X	2.24-2	5.69-1	4.42-4	1.12-2	7.77-3	1.97-1	-1.10-2	-2.79-1
	1.93	Y	3.53-1	8.97+0	3.53-1	8.97+0	3.03-1	7.70+0	3.03-1	7.70+0
		Z	-2.48-1	-6.30+0	-3.37-1	-8.56+0	-2.76-1	-7.01+0	-3.52-1	-8.94+0
		R	4.31-1	1.09+1	4.88-1	1.24+1	4.10-1	1.04+1	4.64-1	1.18+1

Table III. Damage to Left Side of Helicopter Tail Boom Constructed of Aluminum Alloy

Nomenclature	Material Lost lb/kg	Direction	Grid Point Displacements							
			67		70		71		72	
			in.	mm	in.	mm	in.	mm	in.	mm
0	.0	X	2.18-2	5.54-1	2.45-3	6.22-2	7.52-3	1.91-1	-1.23-2	-3.12-1
	.0	Y	3.30-1	8.38+0	3.30-1	8.38+0	3.23-1	8.20+0	3.23-1	8.20+0
		Z	-2.22-1	-5.64+0	-2.47-1	-6.27+0	-2.46-1	-6.25+0	-2.70-1	-6.86+0
		R	3.98-1	1.01+1	4.12-1	1.05+1	4.06-1	1.03+1	4.21-1	1.07+1
1	.35	X	2.27-2	5.77-1	2.84-3	7.21-2	8.15-3	2.07-1	-1.20-2	-3.05-1
	.16	Y	3.38-1	8.59+0	3.38-1	8.59+0	3.31-1	8.41+0	3.31-1	8.41+0
		Z	-2.24-1	-5.69+0	-2.50-1	-6.35+0	-2.50-1	-6.35+0	-2.74-1	-6.96+0
		R	4.05-1	1.02+1	4.20-1	1.07+1	4.15-1	1.05+1	4.30-1	1.09+1
2	.88	X	2.38-2	6.05-1	3.24-3	8.23-2	9.33-3	2.37-1	-1.15-2	-2.92-1
	.40	Y	3.52-1	8.94+0	3.52-1	8.94+0	3.46-1	8.79+0	3.46-1	8.79+0
		Z	-2.24-1	-5.69+0	-2.49-1	-6.32+0	-2.46-1	-6.25+0	-2.73-1	-6.93+0
		R	4.17-1	1.06+1	4.31-1	1.09+1	4.26-1	1.08+1	4.41-1	1.12+1
3	.78	X	2.34-2	5.94-1	3.15-3	8.00-2	8.69-3	2.21-1	-1.18-2	3.00-1
	.35	Y	3.44-1	8.74+0	3.44-1	8.74+0	3.38-1	8.59+0	3.38-1	8.59+0
		Z	-2.26-1	-5.74+0	-2.51-1	-6.38+0	-2.51-1	-6.38+0	-2.75-1	-6.99+0
		R	4.12-1	1.05+1	4.26-1	1.08+1	4.21-1	1.07+1	4.36-1	1.11+1
4	1.18	X	2.49-2	6.32-1	3.69-3	9.37-2	1.02-2	2.59-1	-1.12-2	-2.84-1
	.54	Y	3.61-1	9.17+0	3.61-1	9.17+0	3.56-1	9.04+0	3.56-1	9.04+0
		Z	-2.26-1	-5.74+0	-2.52-1	-6.40+0	-2.52-1	-6.40+0	-2.76-1	-7.01+0
		R	4.26-1	1.08+1	4.40-1	1.12+1	4.36-1	1.11+1	4.50-1	1.14+1
5	1.49	X	2.52-2	6.40-1	3.74-3	9.50-2	1.05-2	2.67-1	-1.11-2	-2.82-1
	.68	Y	3.64-1	9.25+0	3.64-1	9.25+0	3.59-1	9.12+0	3.59-1	9.12+0
		Z	-2.24-1	-5.69+0	-2.50-1	-6.35+0	-2.50-1	-6.35+0	-2.74-1	-6.96+0
		R	4.27-1	1.08+1	4.42-1	1.12+1	4.37-1	1.11+1	4.52-1	1.15+1

Table III cont. Damage to Left Side of Helicopter Tail Boom Constructed of Aluminum Alloy

Nomen-clature	Material Lost lb/kg	Direc-tion	Grid Point Displacements							
			67		70		71		72	
			in.	mm	in.	mm	in.	mm	in.	mm
6	2.08	X	2.58-2	6.55-1	3.83-3	9.73-2	1.13-2	2.87-1	-1.07-2	-2.72-1
	.94	Y	3.72-1	9.45+0	3.72-1	9.45+0	3.68-1	9.35+0	3.68-1	9.35+0
		Z	-2.19-1	-5.56+0	-2.45-1	-6.22+0	-2.44-1	-6.20+0	-2.69-1	-6.83+0
		R	4.32-1	1.10+1	4.45-1	1.13+1	4.42-1	1.12+1	4.56-1	1.16+1
7	3.18	X	2.44-2	6.20-1	1.79-3	4.55-2	5.87-3	1.49-1	-1.29-2	-3.28-1
	1.44	Y	3.51-1	8.92+0	3.51-1	8.92+0	3.03-1	7.70+0	3.03-1	7.70+0
		Z	-1.38-1	-3.51+0	-2.23-1	-5.66+0	-1.71-1	-4.34+0	-2.45-1	-6.22+0
		R	3.77-1	9.58+0	4.16-1	1.06+1	3.48-1	8.84+0	3.90-1	9.91+0
8	4.25	X	2.48-2	6.30-1	1.94-3	4.93-2	6.23-3	1.58-1	-1.26-2	-3.20-1
	1.93	Y	3.53-1	8.97+0	3.53-1	8.97+0	3.03-1	7.70+0	3.03-1	7.70+0
		Z	-1.34-1	-3.40+0	-2.22-1	-5.64+0	-1.68-1	-4.27+0	-2.46-1	-6.25+0
		R	3.78-1	9.60+0	4.17-1	1.06+1	3.46-1	8.79+0	3.88-1	9.86+0

MPa (7.81 x 10^6 psi) for the plate elements and 6.43 x 10^4 MPa (9.32 x 10^6 psi) for the beam elements. A mass density of 1.603x10^3 kg/m^3 (0.00015 lb $sec^2/in.^4$) was used for the beam and plate elements. The total displacements for the various damage configurations for the right side of a tail boom constructed of T300/5208 composite are compiled in Table IV. The maximum displacements of the reference grid points was 17.0 mm (0.668 in.). Figure 10 is a graph of the relative displacement of points on the rear of the tail boom versus composite material lost through simulated projectile damage to the right side. For the same amount of damage loss of weight, the displacements for aluminum are less than for composite material, as is to be expected, since the aluminum has a higher modulus. The nonlinearity of response sets in at above 0.4 kg (0.88 lb) for the composite, less than for aluminum, for the same reason, lower modulus. Table V is a tabulation of displacements versus material lost on the left side of the tail boom. The maximum displacement of the reference grid points is 14.2 mm (0.558 in.). Figure 11 is a graph of displacements versus material lost due to damage to the left side of the tail boom constructed of T300/5208 composite material. The response again appears to flatten out after rising linearly with weight loss. The effect of the lower modulus of the composite compared to aluminum is apparent as the change in response takes place at a lower weight loss.

Note that the points for configurations with nomenclature 7 and 8 were not plotted on the graphs. Since the damage for these configurations was to the rear left and right side of the helicopter tail boom the response was very different from that for damage to the front. Plotting them on the same graphs would not be relevant. Suffice to say that, although the damage loss of material was greater, the deflection response was less than for damage to the front side. The weakened structure gives at the point of damage and the deflection transmitted through a lever arm that is the length of the tail boom from the damaged frontal area, gives a larger deflection at the rear than for an equivalent amount of yielding at the rear damage transmitted through the smaller lever arm.

The undamaged configuration, nomenclature 0, in Tables IV and V show displacement differences amounting to between 2.5 and 3.2 percent due to using the compressive moduli in one calculation and the tensile moduli in the other. The differences in displacements amount to 0.4 mm (0.016 in.) at all four points, a negligible amount of difference.

In a test program conducted by Bell Helicopter Company[4] in 1975 to reduce the vulnerability of the tail boom, the effect of misalignment on the tail rotor drive shaft was analyzed. The analysis was based on the

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[4] D.A. Reisdorfer: "TailBoom Vulnerability Reduction Test Program, Interim Report No. 1, Volume I," Report No. 699-099-004, Aug. 1975, Boeing Helicopter Company, Ft. Worth, TX

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	in.	mm.
[illegible]	[illegible]	X	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.56-2	[illegible]
	[illegible]	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.12-1	[illegible]
		Z	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.46-1	[illegible]
		R	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.38-1	[illegible]
[illegible]	[illegible]	X	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.61-2	[illegible]
	[illegible]	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.19-1	[illegible]
		Z	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.50-1	-8.89+0
		R	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.46-1	1.39+1
[illegible]	[illegible]	X	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.87-2	[illegible]
	[illegible]	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.49-1	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.68-1	[illegible]
		R	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.81-1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.66-2	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.25-1	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.57-1	[illegible]
		R	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.55-1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.88-2	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.50-1	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.75-1	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.86-1	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.05-2	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.67-1	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.97-1	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.13-1	[illegible]

Table IV cont. Damage to Right Side of Helicopter Tail Boom Constructed of T300/5208 Composite

Nomenclature	Material Loss lb kg	Direction	Grid Point Displacements							
			67		70		71		72	
			in.	mm	in.	mm	in.	mm	in.	mm
6	2.34	X	2.70-2	6.86-1	-4.58-3	-1.16-1	5.94-3	1.51-1	-2.52-2	-6.40-1
	1.06	Y	5.24-1	1.33+1	5.24-1	1.33+1	5.15-1	1.31+1	5.15-1	1.31+1
		Z	-3.46-1	-8.79+0	-3.93-1	-9.98+0	-3.83-1	-9.73+0	-4.26-1	-1.08+1
		R	6.28-1	1.60+1	6.55-1	1.66+1	6.42-1	1.63+1	6.68-1	1.70+1
7	1.91	X	2.87-2	7.29-1	-3.00-5	-7.62-4	1.00-2	2.54-1	-1.39-2	-3.53-1
	.87	Y	4.46-1	1.13+1	4.46-1	1.13+1	3.89-1	9.88+0	3.89-1	9.88+0
		Z	-3.07-1	-7.80+0	-4.13-1	-1.05+1	-3.42-1	-8.69+0	-4.32-1	-1.10+1
		R	5.42-1	1.38+1	6.08-1	1.54+1	5.18-1	1.32+1	5.81-1	1.48+1
8	2.55	X	2.85-2	7.24-1	-5.14-4	-1.32-2	9.64-3	2.45-1	-1.44-2	-3.66-1
	1.16	Y	4.48-1	1.14+1	4.48-1	1.14+1	3.90-1	9.91+0	3.90-1	9.91+0
		Z	-3.10-1	-7.87+0	-4.17-1	-1.06+1	-3.45-1	-8.76+0	-4.37-1	-1.11+1
		R	5.45-1	1.38+1	6.12-1	1.55+1	5.21-1	1.32+1	5.85-1	1.49+1

Table V. Damage to Left Side of a Helicopter Tail Boom Constructed of T300/5208 Composite

Nomenclature	Material Lost lb/kg	Direction	Grid Point Displacements							
			[illegible]		7		71		72	
			in.	mm	in.	mm	in.	mm	in.	mm
0	.0	X	2.70-2	6.86-1	2.75-3	6.99-2	9.12-3	2.32-1	-1.51-2	-3.84-1
	.0	Y	4.10-1	1.04+1	4.10-1	1.04+1	4.00-1	1.02+1	4.00-1	1.02+1
		Z	-2.72-1	-6.91+0	-3.07-1	-7.80+0	-3.03-1	-7.70+0	-3.36-1	-8.53+0
		R	4.93-1	1.25+1	5.12-1	1.30+1	5.02-1	1.27+1	5.23-1	1.33+1
1	.21	X	2.80-2	7.11-1	3.19-3	8.10-2	9.83-3	2.50-1	-1.49-2	-3.78-1
	.10	Y	4.18-1	1.06+1	4.18-1	1.06+1	4.10-1	1.04+1	4.10-1	1.04+1
		Z	-2.75-1	-6.99+0	-3.11-1	-7.90+0	-3.06-1	-7.77+0	-3.40-1	-8.64+0
		R	5.01-1	1.27+1	5.21-1	1.[illegible]+1	5.12-1	1.30+1	5.33-1	1.35+1
2	.53	X	2.95-2	7.49-1	3.68-3	9.35-2	1.13-2	2.87-1	-1.43-2	-3.63-1
	.24	Y	4.35-1	1.10+1	4.35-1	1.10+1	4.28-1	1.09+1	4.28-1	1.09+1
		Z	-2.76-1	-7.01+0	-3.12-1	-7.92+0	-3.08-1	-7.82+0	-3.42-1	-8.69+0
		R	5.15-1	1.31+1	5.34-1	1.35+1	5.26-1	1.34+1	5.46-1	1.39+1
3	.47	X	2.88-2	7.32-1	3.55-3	9.02-2	1.04-2	2.64-1	-1.42-2	-3.61-1
	.21	Y	4.26-1	1.08+1	4.26-1	1.08+1	4.18-1	1.06+1	4.18-1	1.06+1
		Z	-2.76-1	-7.01+0	-3.12-1	-7.92+0	-3.08-1	-7.82+0	-3.42-1	-8.69+0
		R	5.08-1	1.29+1	5.28-1	1.34+1	5.19-1	1.32+1	5.40-1	1.37+1
4	.71	X	3.07-2	7.80-1	4.18-3	1.06-1	1.22-2	3.10-1	-1.40-2	-3.56-1
	.32	Y	4.46-1	1.13+1	4.46-1	1.13+1	4.40-1	1.12+1	4.40-1	1.12+1
		Z	-2.76-1	-7.01+0	-3.13-1	-7.95+0	-3.08-1	-7.82+0	-3.42-1	-8.69+0
		R	5.25-1	1.33+1	5.45-1	1.38+1	5.37-1	1.36+1	5.57-1	1.41+1
5	.89	X	3.10-2	7.87-1	4.24-3	1.08-1	1.26-2	3.20-1	-1.38-2	-3.51-1
	.41	Y	4.50-1	1.14+1	4.50-1	1.14+1	4.43-1	1.13+1	4.43-1	1.13+1
		Z	-2.73-1	-6.93+0	-3.10-1	-7.87+0	-3.05-1	-7.75+0	-3.39-1	-8.61+0
		R	5.27-1	1.34+1	5.46-1	1.39+1	5.38-1	1.37+1	5.58-1	1.42+1

Table V Cont. Damage to Left Side of Helicopter Tail Boom Constructed of T300/5208 Composite

Nomen-clature	Material Lost lb/kg	Direc-tion	Grid Point Displacements							
			67		70		71		72	
			in.	mm	in.	mm	in.	mm	in.	mm
6	1.25	X	3.18-2	8.08-1	4.36-3	1.18-8	1.37-2	3.48-1	-1.32-2	3.35-1
	.57	Y	4.61-1	1.17+1	4.61-1	1.17+1	4.55-1	1.16+1	4.55-1	1.16+1
		Z	-2.67-1	-6.78+0	-3.04-1	-7.72+0	-2.99-1	-7.59+0	-3.22-1	-8.18+0
		R	5.33-1	1.35+1	5.52-1	1.40+1	5.45-1	1.38+1	5.58-1	1.42+1
7	1.91	X	2.99-2	7.59-1	2.02-3	5.13-2	7.33-3	1.86-1	-1.59-2	-4.04-1
	.87	Y	4.33-1	1.10+1	4.33-1	1.10+1	3.78-1	9.60+0	3.78-1	9.60+0
		Z	-1.79-1	-4.55+0	-2.81-1	-7.14+0	-2.20-1	-5.59+0	-3.07-1	-7.80+0
		R	4.69-1	1.19+1	5.16-1	1.31+1	4.37-1	1.11+1	4.87-1	1.24+1
8	2.55	X	3.03-2	7.07-1	2.20-3	5.59-2	7.81-3	1.98-1	-1.55-2	-3.94-1
	1.16	Y	4.35-1	1.10+1	4.35-1	1.10+1	3.78-1	9.60+0	3.78-1	9.60+0
		Z	-1.75-1	-4.45+0	-2.79-1	-7.09+0	-2.16-1	-5.49+0	-3.05-1	-7.75+0
		R	4.69-1	1.19+1	5.17-1	1.31+1	4.35-1	1.11+1	4.86-1	1.23+1

limiting stress level of the couplings in the drive shaft using experience from studies of other couplings. The coupling set was analyzed for the cruise condition of the helicopter which would require 40 HP through the tail rotor drive system. Results indicated that for the helicopter to maintain a sustained cruise, and then hover long enough to land, the maximum coupling misalignment that could be tolerated would be 2.5 degrees. Using the fact that the tail rotor drive shaft is supported at stations 143.3 and slightly aft of station 194.3, an incremental deflection of 56.6 mm (2.23 in.) was calulated as the maximum that could be tolerated between these two stations for extended cruise conditions. An even greater deflection would then occur at tail boom station 227.0 due to the additional lever arm. The deflections that were calculated in the present study with the damage inflicted are considerably lower than the above figures. However, a NASTRAN model of the tail boom would be expected to be stiffer than an experimental counterpart. Among other possible reasons are that the model has no slippage at rivet points, and the skin is not permitted to buckle and so is stiffer.

A further consideration is that the tail boom constructed of aluminum alloy had a structural weight of 57.7 kg (127.1 lb), and in the model additional nonstructural weight amounting to 24.0 kg (52.9 lb) was distributed along the length of the tail boom. Replacement by the lighter weight composite would result in a weight saving of from 23.1 kg (50.9 lb) to 32.7 kg (72.0 lb), depending upon to what extent the aluminum alloy could be replaced by the composite material. This reduction in weight could make the helicopter more maneuverable or better able to carry a larger payload. Another consideration is whether use of the more expensive ultra-modulus composite, *with a modulus almost twice that* of T300/5208 and about 50% greater than the aluminum alloy, is warranted. The density of the ultra-modulus graphite/epoxy is only about two percent greater than that of T300/5208 and therefore the weight savings would be comparable.

IV. CONCLUSION

The investigation, using the NASTRAN code showed that the loss of rigidity due to simulated projectile damage was not sufficient to result in misalignment of the rotor drive shaft to a degree that would result in failure of the drive shaft coupling for tailbooms of aluminum or of T300/5208 graphite/epoxy composite material. While the T300/5208 tail boom was less rigid, the calculations indicated displacements that were not sufficient to cause drive shaft failure according to the criterion set by the Bell study.

The composite material part of the problem was treated by simply changing the material constants from those of aluminum to those of the composite. It is probable that if a tail boom is designed using fibrous composite material that the construction of the tail boom would result in a considerably different structure than the skin plates, stringers,

longerons and bulk heads that are used in the aluminum alloy design. It would also be of interest to compare the responses of composite and aluminum alloy structures for explosive projectiles like the 23 mm. Would the damage be greater or less per hit? Would the blast result in considerable delamination which would seriously affect the integrity of the structure? Another factor is, of course, the cost, not only of the materials themselves but also of fabrication of the structure. In the final decision as to which material to use, all of the above factors must be considered.

Conducting an experiment to evaluate the actual deflection under load of a model closely approximating the one used in the NASTRAN calculations would also be useful.

ACKNOWLEDGMENTS

Dr. Ennis F. Quigley was the contract officer's representative on the contract that resulted in the generation of the model of the UH-1B tail boom that was used in this investigation. I appreciate his helpful discussions with regard to the model that was developed. Mr. Thomas F. Erline contributed helpful discussions on the use of the UNIVAC computer, Hazletine terminal, and UNIVAC version of the NASTRAN program. My thanks also to the operating staff of the UNIVAC computer who expedited many runs and aided me in getting past some of the blocks caused by inexperience with that specific computer. I take this opportunity to acknowledge the assistance of Mr. Wyatt K. Wallace and Ms. Joan H. Walter, Applications Support and Mr.Robert J. Hartman and Mr. Robert E. Amos, Techniques Science and Engineering at the Edgewood area UNIVAC installation on this and earlier projects. My thanks also to Dr. Donald F. Haskell, team leader of the Army Aircraft Systems Team, for helpful discussions and supplying me with useful reports, references, and papers.

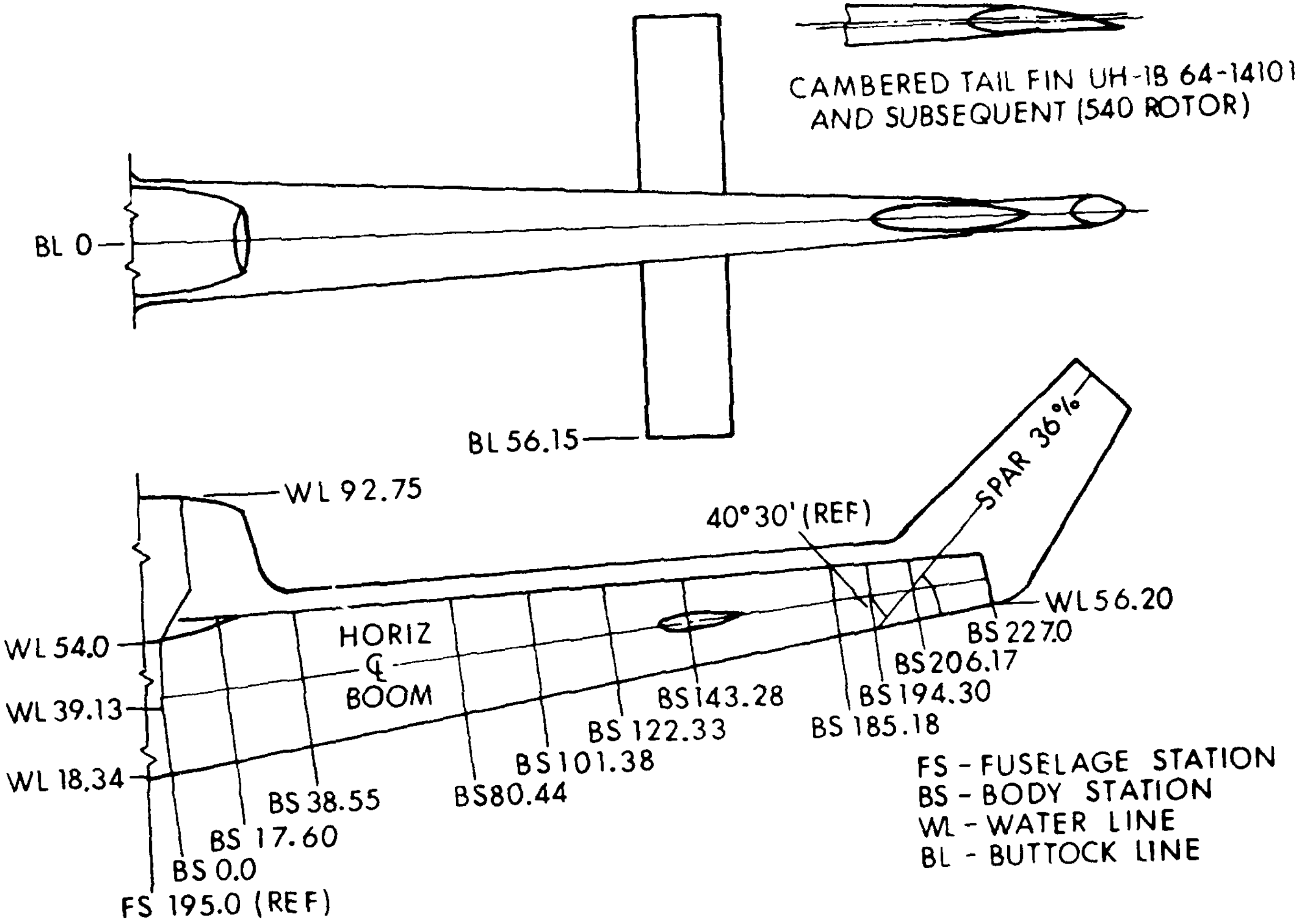

Figure 1. UH-1B Tail Boom; Side, Front Views and Stations

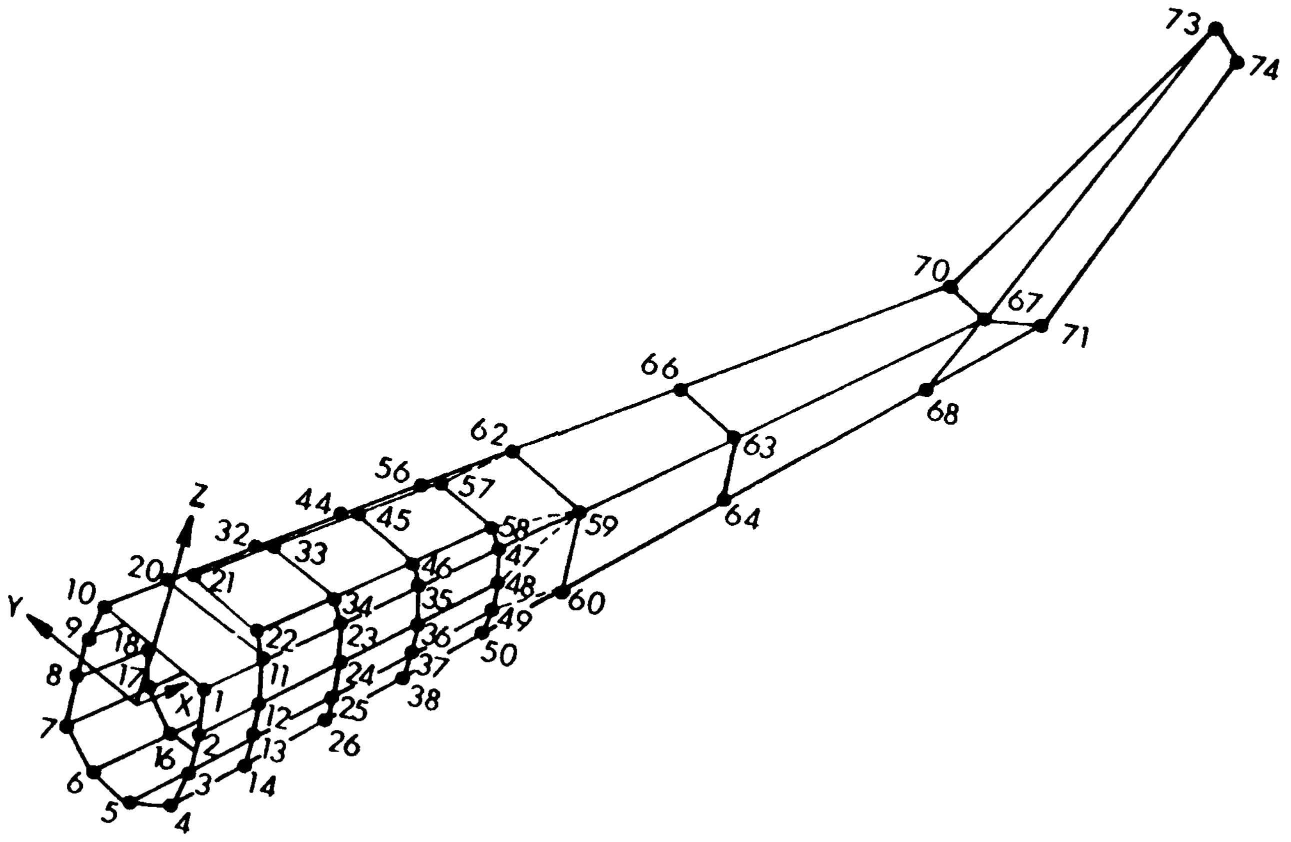

Figure 2. UH-1B Tail Boom Model Grid Points and Numbering Scheme

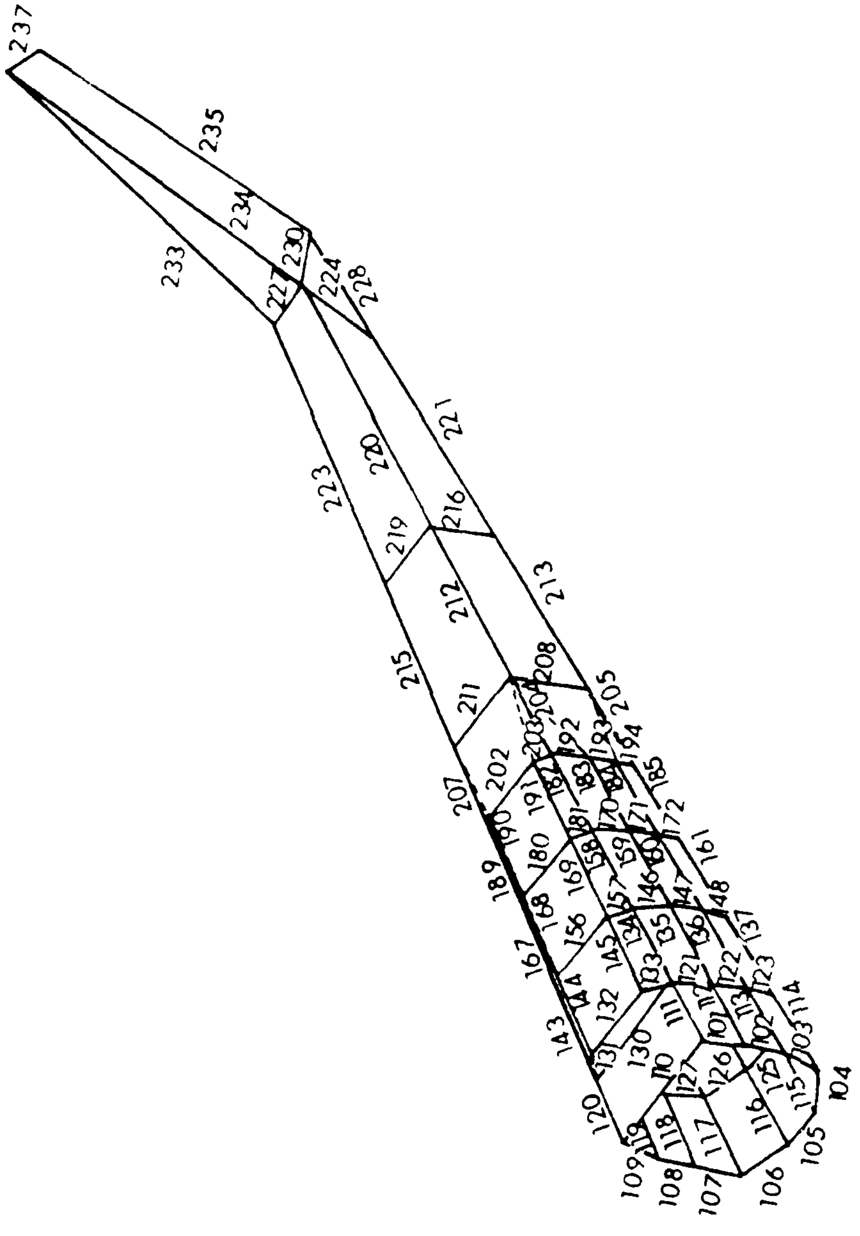

Figure 3. UH-1F Tail Boom Model Beam Element Identification

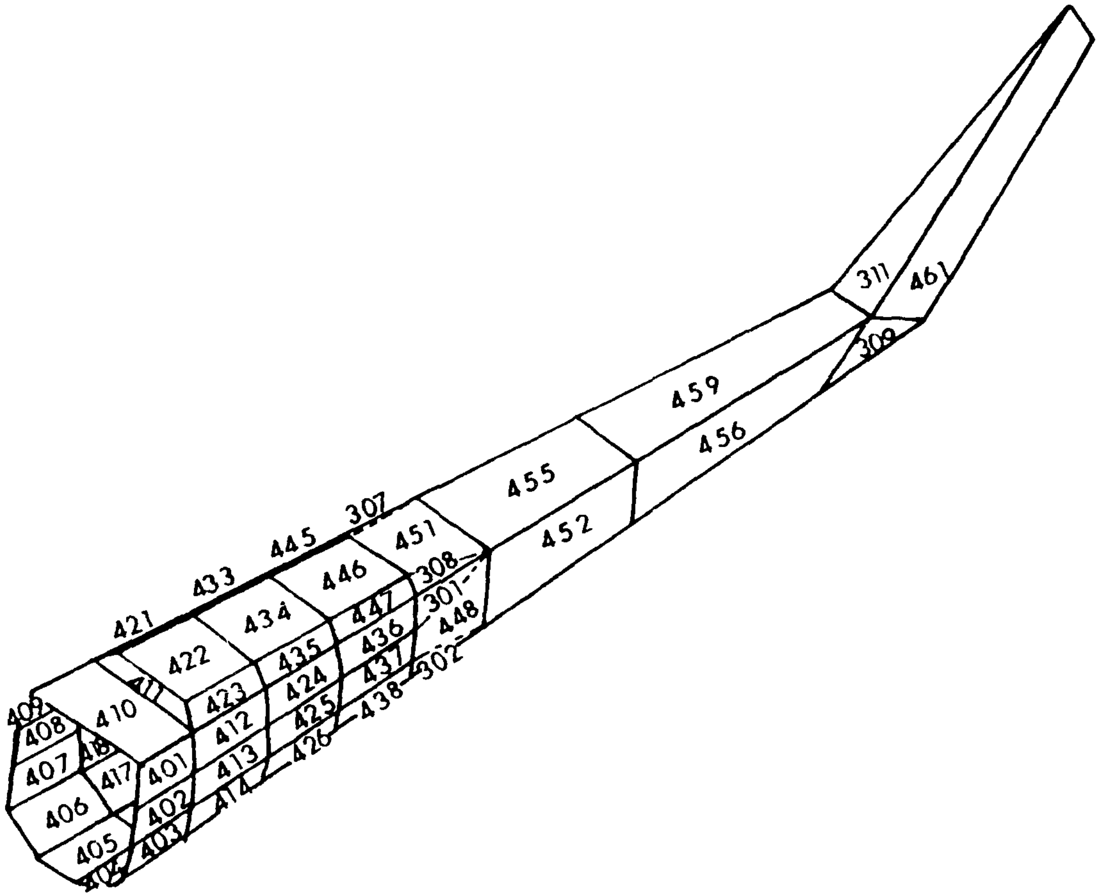

Figure 4. UH-1B Tail Boom Model Plate Element Identification

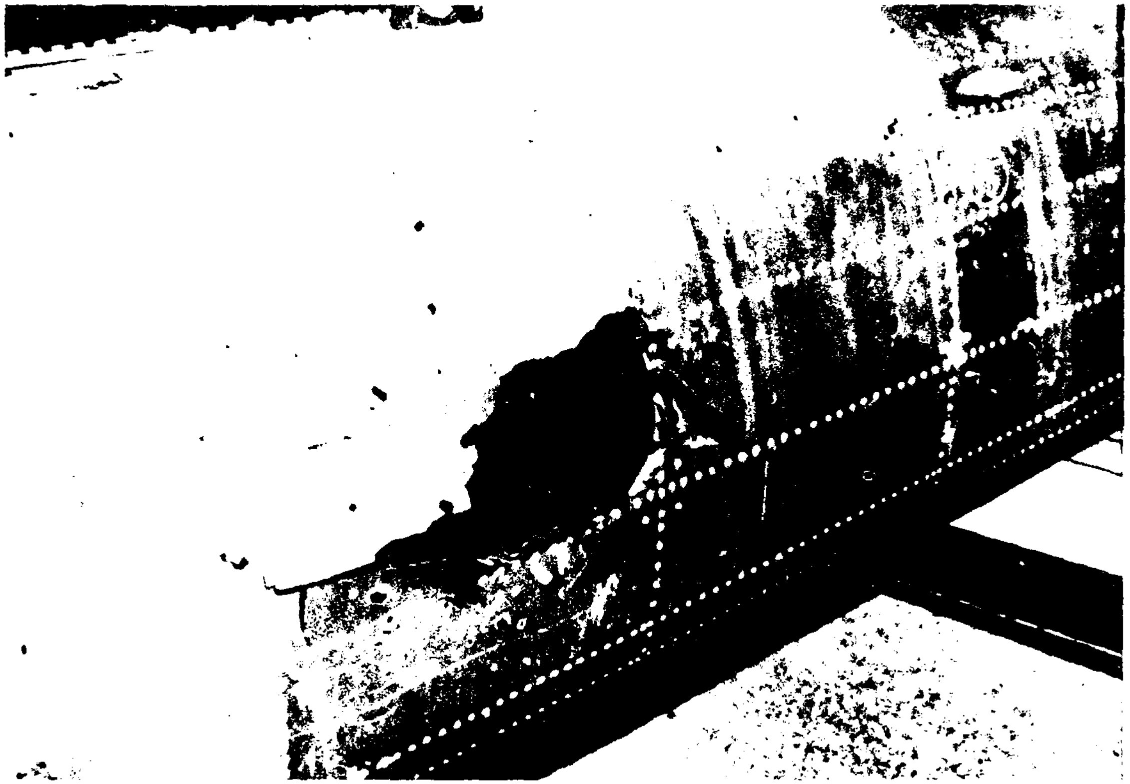

Figure 5. Damage to Left Side from Single 23 mm Explosive Projectile Hit on Forward Right Side of Tail Boom

Figure 6. Damage to Left Side from Two 23 mm Explosive Projectile Hits on Forward Right Side of Tail Boom

Figure 7. Damage to Left Side from Two 23 mm Explosive Projectile Hits on Rear Right Side of Tail Boom

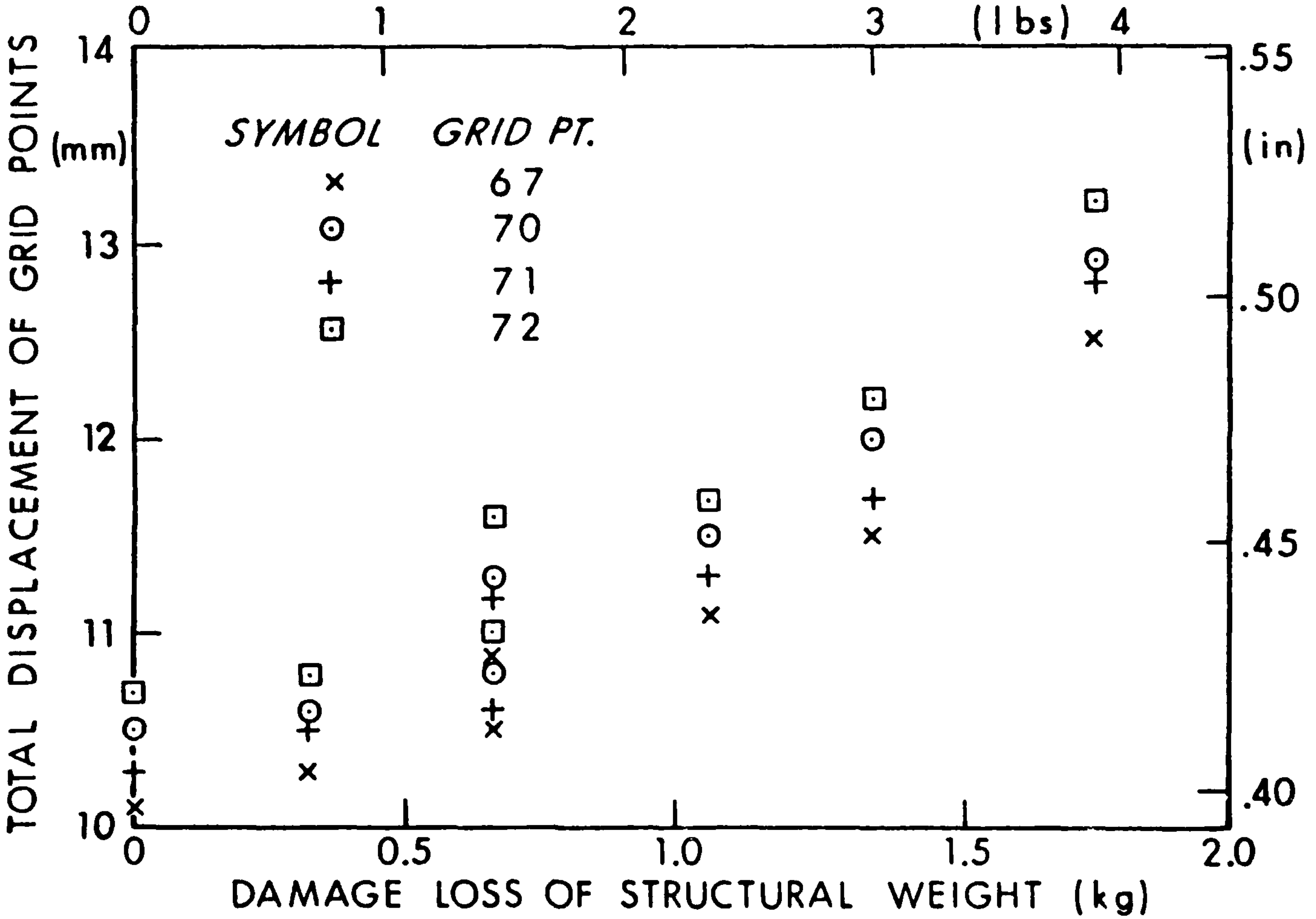

Figure 8. Displacements vs. Damage Weight Loss of Material on Right Side of Tail Boom Constructed of Aluminum Alloy

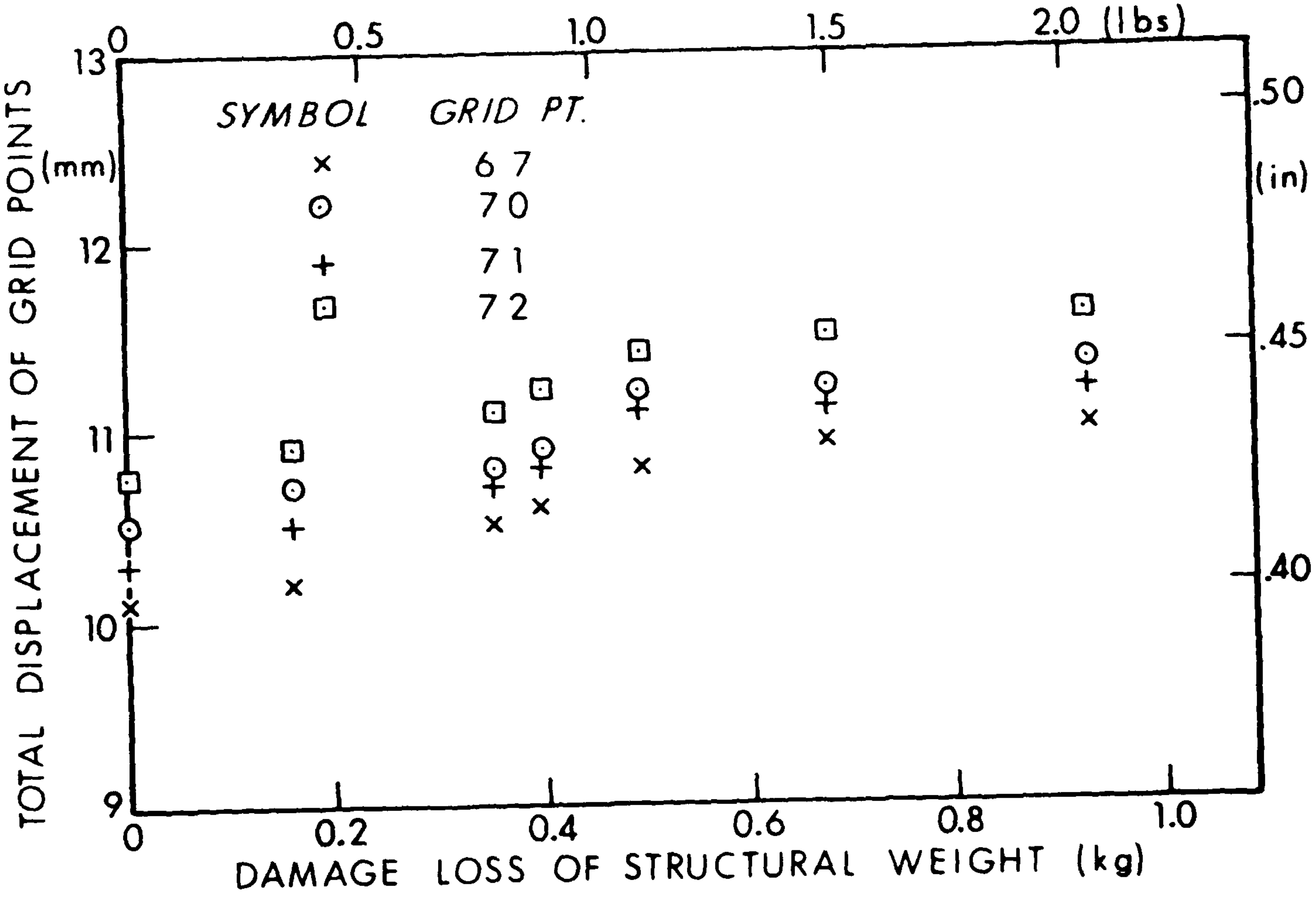

Figure 9. Displacements vs. Damage Weight Loss of Material on Left Side of Tail Boom Constructed of Aluminum Alloy

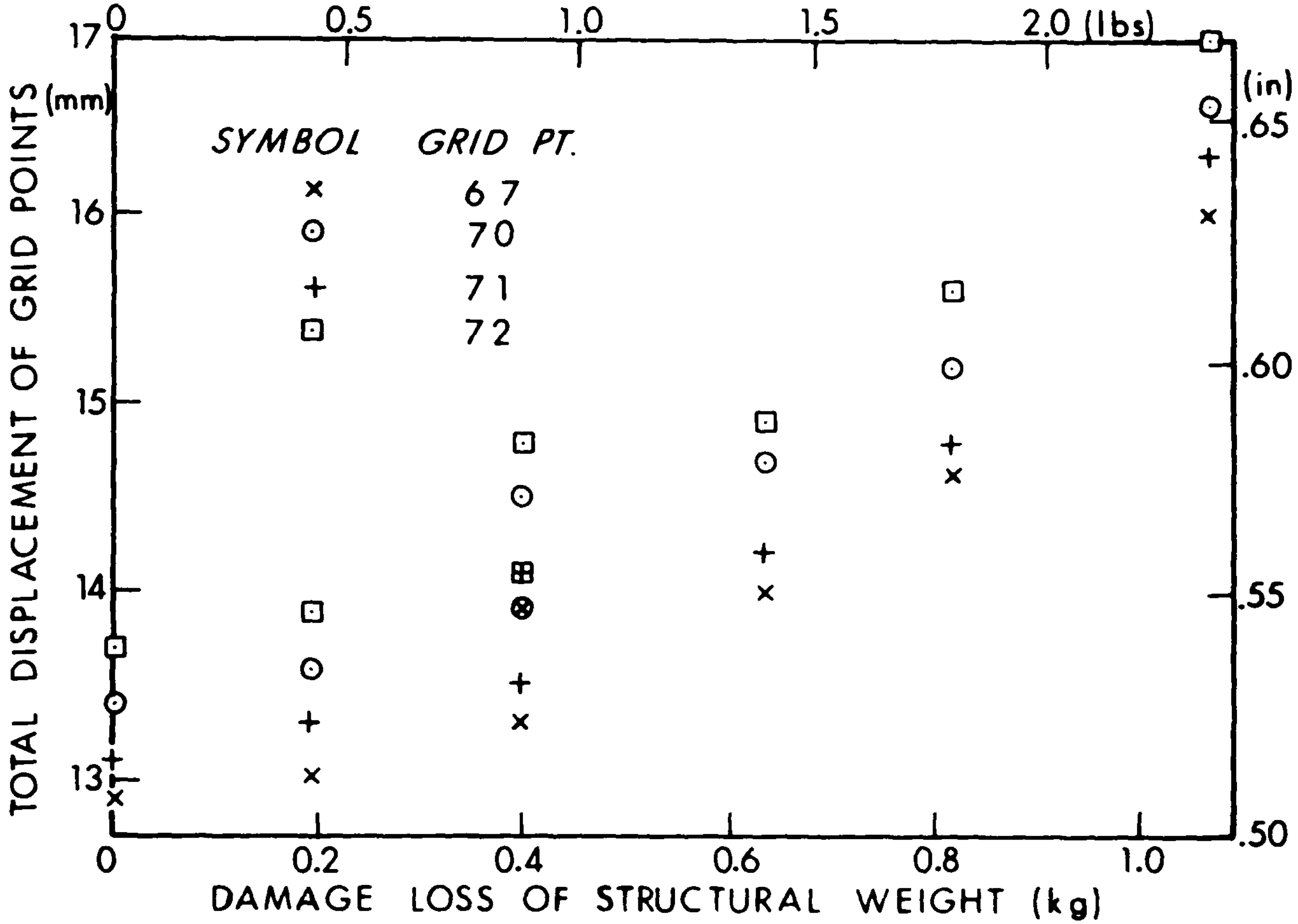

Figure 10. Displacements vs. Damage Weight Loss of Material on Right Side of Tail Boom Constructed of T300/5208 Graphite/Epoxy Composite

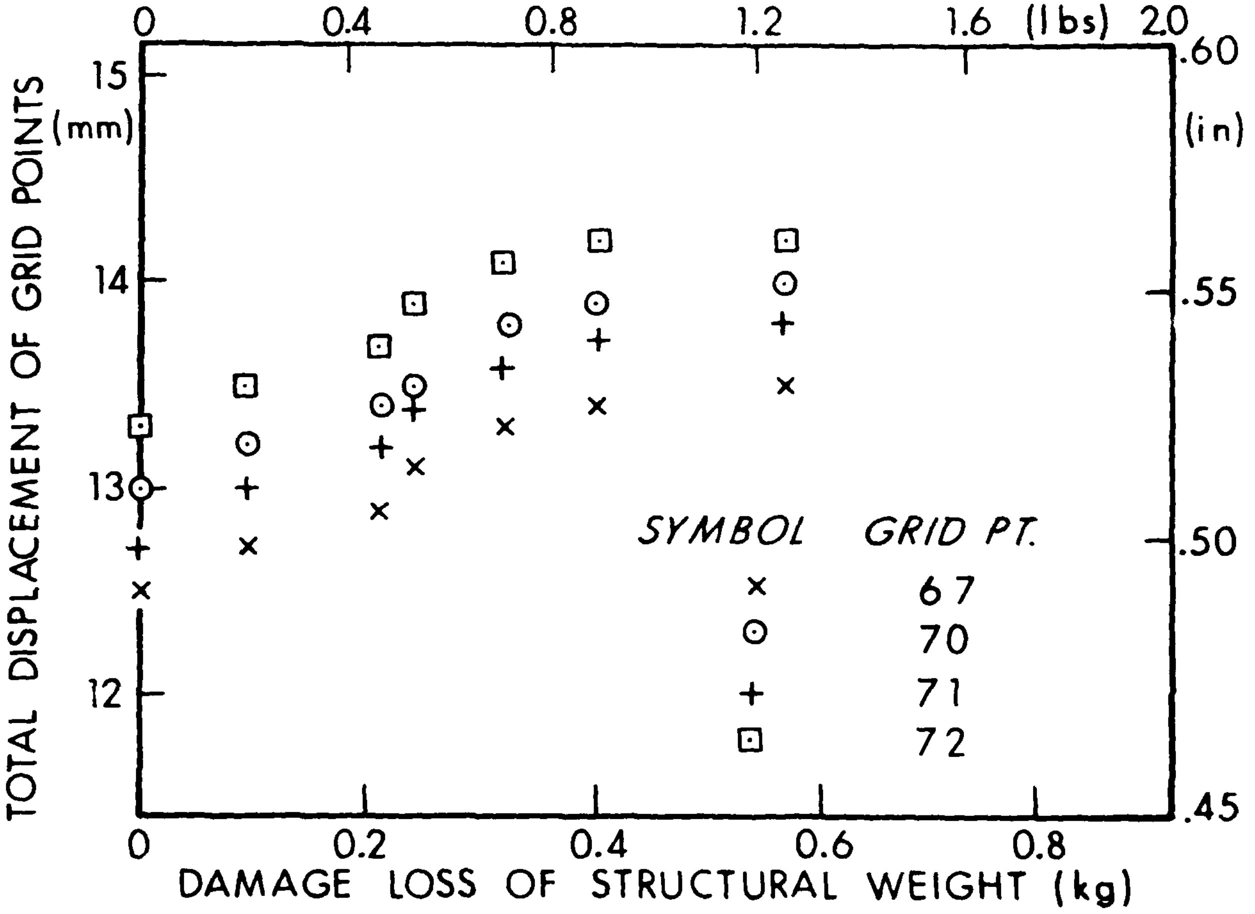

Figure 11 Displacements vs. Damage Weight Loss of Material on Left Side of Tail Boom Constructed of T300/5208 Graphite/Epoxy Composite

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